"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power System)"

Signature : ______________________________

Name : MUHAMAD ZAHIM BIN SUJOD

Date : 17 NOVEMBER 2008

SINGLE PHASE MOTOR SPEED CONTROL
USING SPWM INVERTER

SITI FAIRUZ BINTI HAMID

This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Power System)

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Universiti Malaysia Pahang

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Signature : ______________________________

Author : SITI FAIRUZ BINTI HAMID

Date : 17 NOVEMBER 2008

Dedicated to my beloved mother, brothers,grandmother,and Sisters-in-laws

Che Esah Bt Musa

Thanks for the love and supports

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ABSTRACT

An inverter circuit by using Sinusoidal Pulse Width Modulation (SPWM) switching schemes is developed to control the speed of single-phase AC motor and being verified experimentally. Inverters are circuit that convert a DC source to an AC source. DC is one type of energy found in batteries and AC is a type of energy that is produced by the power company and found in electrical homes/offices appliances. The application of this AC motor controller is to provide single-phase ac induction motor less than ½ hp (372.85 W). Semiconductor device, Metal Oxide Field Effect Transistor (MOSFET) is used as switch in the full bridge (H-bridge) inverter configuration with unipolar voltage switching. A variable frequency output waveform is produced by the inverter to run a motor at variable speeds that are directly proportional to this frequency. Besides the MOSFETs as the inverter, driver for the MOSFET also very important in this circuit development because it is use to interface between control circuits (low voltage part) and inverter (high voltage part). Another important part in this inverter design is PICmicro microcontroller chip that is used to provide the switching schemes to the MOSFETs. This microchip acts as a controller circuit that produces the carrier signal and modulating signal for the inverter. The objective of this project is to build an ac motor speeds controller for holiday usage appliances, to simulate and analyze the single-phase SPWM operation of the inverter switching characteristics. The Programmable Interface Computer PIC used is PIC 18F4550 and the MOSFET driver used is IR2110. At the end of this project, the SPWM output is developed from the controller circuit and applied to the driver circuit and the inverter, and hence can be used to control the speed of the AC motor.

ABSTRAK

Litar penyongsang dengan menggunakan teknik pemodulatan lebar denyut sinus (SPWM), aturan pensuisan dibina untuk mengawal kelajuan AC fasa tunggal motor dan dibuktikan secara ujikaji. Litar pengongsang adalah litar yang menukarkan sumber arus terus (DC) kepada sumber arus ulang-alik (AC). DC adalah salah suatu tenaga yang boleh dijumpai di dalam bateri (dihasilkan oleh bateri) dan AC pula adalah sumber tenaga yang dihasilkan oleh syarikat pembekalan kuasa dan digunakan oleh alatan elektrik rumah ataupun pejabat. Aplikasi pengawal AC motor ini adalah untuk menyediakan ac motor teraruh fasa tunggal kurang daripada ½ hp (372.85 W). Alat separa pengalir, Metal Oxide Field Effect Transistor (MOSFET) digunakan sebagai suis di dalam topologi litar penyongsang tetimbang penuh (full-bridge/ H-bridge) dengan pensuisan unipolar. Gelombang keluaran dengan frekuensi yang berlainan dihasilkan oleh penyongsang untuk menggerakkan motor dengan kelajuan yang berkadar terus dengan frekuensi tersebut. Selain daripada MOSFET yang bertindak sebagai, pemacu MOSFET juga sangat penting dalam pembangunan litar ini kerana ia digunakan sebagai perantaraan antara litar pengawal (voltan rendah) dan penyongsang (voltan tinggi). Suatu lagi bahagian penting di dalam rekaan penyongsang ini adalah mikroPIC,mikropengawal yang digunakan untuk menghasilkan aturan pensuisan kepada MOSFET. Cip mikro ini bertindak sebagai litar pengawal yang menghasilkan isyarat pembawa dan isyarat pemodulat kepada penyongsang. Objektif projek ini adalah untuk merekabentuk litar.mesimulasi dan menganalisa sifat pensuisan penyongsang bagi operasi SPWM fasa tunggal. Programmable Interface Computer (PIC) mikropengawal yang digunakan adalah PIC 18F4450 dan pemacu MOSFET pula adalah IR2110. Pada akhir projek ini, keluaran SPWM telah berjaya dikeluarkan dari PIC mikropengawal dan diaplkasikan kepada litar pengawal dan penyongsang yang boleh digunakan untuk mengawal kelajuan motor AC.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

This chapter will mainly discuss about type of inverters and the basic operation and also the advantages of the SPWM inverter compares to other type of inverter. The objectives, scopes and thesis outline also presented in this chapter.

1.2 OVERVIEW OF THE PROJECT

Inverters are circuits that convert DC to AC. It transfers power from DC source to AC load. The mainly purpose of designing the inverter is to create an AC voltage when only a DC voltage source is available. There are many types of inverters, such as half wave inverter and full wave inverter and they are also can be designed to be single-phase full-bridge (H-bridge) inverter, two-phase inverter and three-phase inverter. The switching schemes that can be produce from full wave inverter are square wave (SW), quasi-square wave (QWS)/modified sine wave and pulse width modulation technique.

The proposed of this project is how to develop a sinusoidal pulse width modulation inverter to control the speed of single phase motor. Square wave inverter has a high harmonic output, which can lead the equipment component to overheat, so no longer relevant for modern use. The modified square wave inverter is designed to have better characteristics than square wave inverter, but it is still cannot give a perfect electrical as pure sine wave. Pulse width modulation (PWM) provides a way to decrease the total harmonic distortion (THD) of load current.

In PWM, the amplitude of the output voltage can be controlled width the modulating waveforms. Reduced filter requirements to decrease harmonics and the control of the output voltage amplitude are two distinct advantages of PWM. The SPWM inverter is the generation of PWM outputs with sine wave as the modulating signal and triangular wave as carrier signal. The on and off occurrence are determined by comparing sinusoidal (modulating) wave with triangular (carrier) wave. The sine waves determine the frequency of the output waveform while the carrier signal determine the switching frequency of the MOSFET.

SPWM technique with filter can produce true sine wave output; hence make it compatible with all AC equipments including the sensitive equipments.

1.3 OBJECTIVES OF THE PROJECT

The objectives of this project are :

i. Develop SPWM Inverter for single phase ac motor application that generates 240Vrms, 50Hz and ½ hp.
ii. Develop an open loop system by using PIC microcontroller to produce SPWM pulse to control speed of motor.
iii. Design circuit, simulate and analyze the switching characteristics of sinusoidal pulse width modulated inverter.

1.4 SCOPES OF THE PROJECT

The scopes of the projects are;

i. To design SPWM inverter to control the speed of single phase motor.
ii. PIC microcontroller is used to control the switching process.
iii. ORCAD Pspice program is used to design and simulate the SPWM inverter circuit.

1.5 THESIS OUTLINE

Chapter 1 explains the operation of an inverter and advantages of SPWM method. The overview of project objectives and project scopes also discuss in this chapter.

Chapter 2 focuses on the literature review that related to this project. The inverter design, driver circuit, theory and also the calculation which is involved in the design and the PIC microcontroller are explain more detail

Chapter 3 discusses about methodology of this project. This chapter also discuss about overall circuit design and the system work. The software used and the source codes of how to generate SPWM from PIC is explained.

Chapter 4 explains and discusses all the results obtained and the analysis of the overall project. The comparisons of Pspice simulation's results and hardware results are explain more detail.

Chapter 5 discusses the conclusion of the SPWM method that is implemented into the project. This chapter also gives the recommendation about the future development of the inverter projects by making some additional featured to the circuit and the software coding.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 AC Motor and Loads

An inverter is an electronic device which inverts DC energy (the type of energy found in batteries) into AC energy. Household appliances such as refrigerators, TVs , lighting, stereos, computer etc., all run off of AC electricity [?]. An AC motor is an electric motor that is driven by an alternating current. The motor is connected to the mains through an AC switch. The AC voltage varies across the motor in phase control mode by means of a microcontroller, which sets the triggering time. The application example of AC motor load is vacuum cleaner, washing machines power tools and food processors.

Besides that, small single-phase AC motors are usually used to power mechanical clocks, audio turntables, and tape drives; formerly they were also much used in accurate timing instruments such as strip-chart recorders or telescope drive mechanisms [a].

2.2 Inverters

There are many type of inverters have been developed. But the most common inverters and are square wave inverter, modified square wave inverter and pure sine wave inverter.

Mobility and versatility have become a must for the fast-paced society today. People can no longer afford to be tied down to a fixed power source location when using their equipments. Overcoming the obstacle of fixed power has led to the invention of DC/AC power inverters. While the position of power inverter in the market is relatively well established, there are several features that can be improved upon.

A comparison analysis of the different power inverter has been compiled. Aside from the differences in power wattage, cost per wattage, efficiency and harmonic contend, power inverters can be categorized into three groups: square wave, modified sine wave, and pure sine wave.

2.2.1 Square Wave Inverter

Power inverters of first designed are inverters using a square wave as the output form. This led to many different problems involving the functionality of devices that were being powered because they were designed to work with a sine wave instead of a square wave. These old-fashioned inverters are the cheapest to make, but the hardest to use. They just flip the voltage from plus to minus creating a square waveform. They are not very efficient because the square wave has a lot of power in higher harmonics that cannot be used by many appliances.

2.2.2 Modified Square Wave Inverter

The modified sine wave is designed to minimize the power in the harmonics while still being cheap to make. There were some changes made to the hardware to eliminate the harsh corners from the square wave to transform it to a “modified sine wave”. Modified square wave can have detrimental effects on electrical loads. First of all, abnormal heat will be produced, causing a reduction in product reliability, efficiency, and useful life. Another disadvantage of a “modified sine wave” is that its choppy waveform can confuse the operation of some digital timing devices. This can cause a device to perform undesirable or abnormal functions. Also, nearly 5 % of household electronics will not even work with a modified sine wave.

Appliances that are known to have problems with the modified sine wave are some digital clocks, some battery chargers, light dimmers, some battery operated gadgets that recharge in an AC recepticle, some chargers for hand tools (Makita is known to have this problem). In the case of hand tools, the problem chargers usually have a warning label stating that dangerous voltages are present at the battery terminals when charging.

2.2.3 Pure Sine Wave Inverter

A pure sine wave inverter produces power that is exactly like the power which is produced by the utility company without the spikes and brownout of course. This type of inverter produces pure sine waves at the cost of some efficiency loss and at a much higher price compares to modified sine wave inverter. In fact, most pure sine wave inverters are typically priced at least 75% higher than their modified sine wave counterparts [2].

Modulation techniques are used in inverter to regulate output voltage/current. The type of pulse width modulation technique used decides the switching losses in the inverter, harmonic contents in output waveform, and overall performance of the inverter. Sine wave pulse width modulation (SPWM) is most widely used scheme due to its simplicity and better output profile.

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a microprocessor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion [2].

Control of the switches for sinusoidal PWM requires (1) a reference signal, sometimes called a modulating or control signal, which is a sinusoid in this case; and (2) a carrier signal, which is a triangular wave that controls the switching frequency [1].

In Sinusoidal Pulse Width Modulation, SPWM, multiple pulses are generated, each having different width time. The width of each pulse is varied in proportion to the instantaneous integrated value of the required fundamental component at the time of its event. In other words, the pulse width becomes a sinusoidal function of the angular position. The repetition frequency of the output voltage will be a frequency higher than the fundamental. In applying SPWM, the lower order harmonics of the modulated voltage wave are highly reduced in contrast to the use of uniform pulse width modulation [5].

2.2.3.1 SPWM Inverter – Bipolar Switching

The graph below shows the harmonic distortion that occurs by using bipolar PWM switching. Bipolar PWM output contains either +V or –V always. Because the transition switching involving peak to peak value, hence switching harmonic content in this scheme is more. In addition, the switching harmonic content is the highest when the PWM is trying to generate zero volt output after the averaging filter.It is difficult to synthesise good 'zero crossings' in a bipolar scheme unless heavy filtering(with consequent degradation in response time) is used.

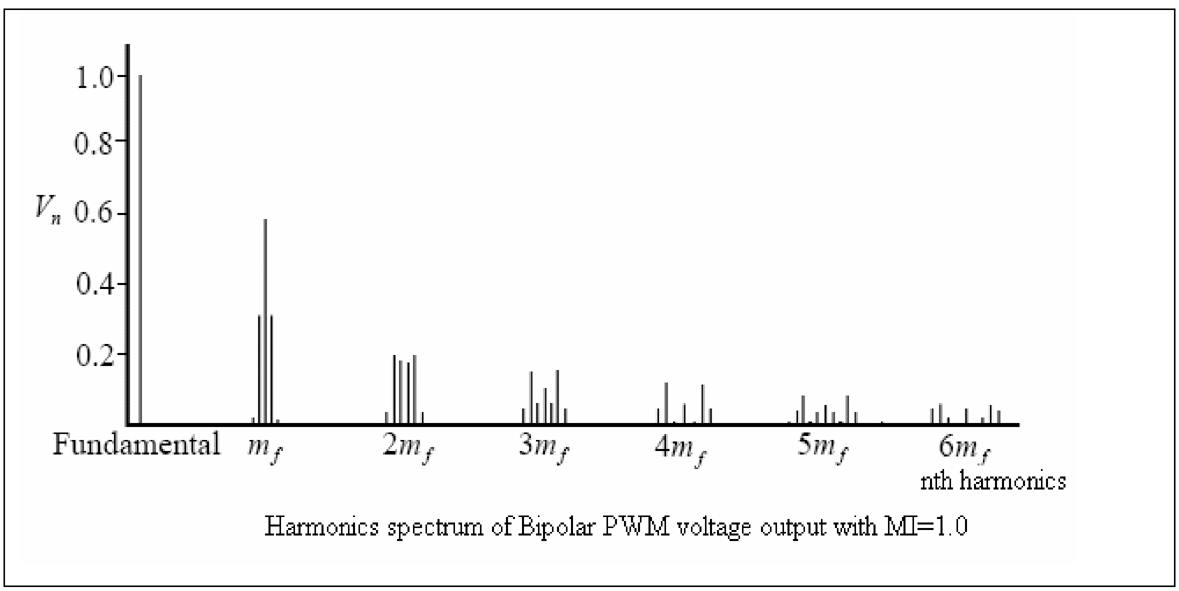

Figure 2.1 : Harmonics Spectrum of Bipolar SPWM

2.2.3.2 SPWM Inverter – Unipolar Switching

The graph below shows the harmonic distortion that occurs with using unipolar PWM switching. Unipolar PWM uses +V and zero to make positive outputs and –V and 0 to make negative outputs. Switching Harmonic Content in this case will be small and will be zero at zero crossings

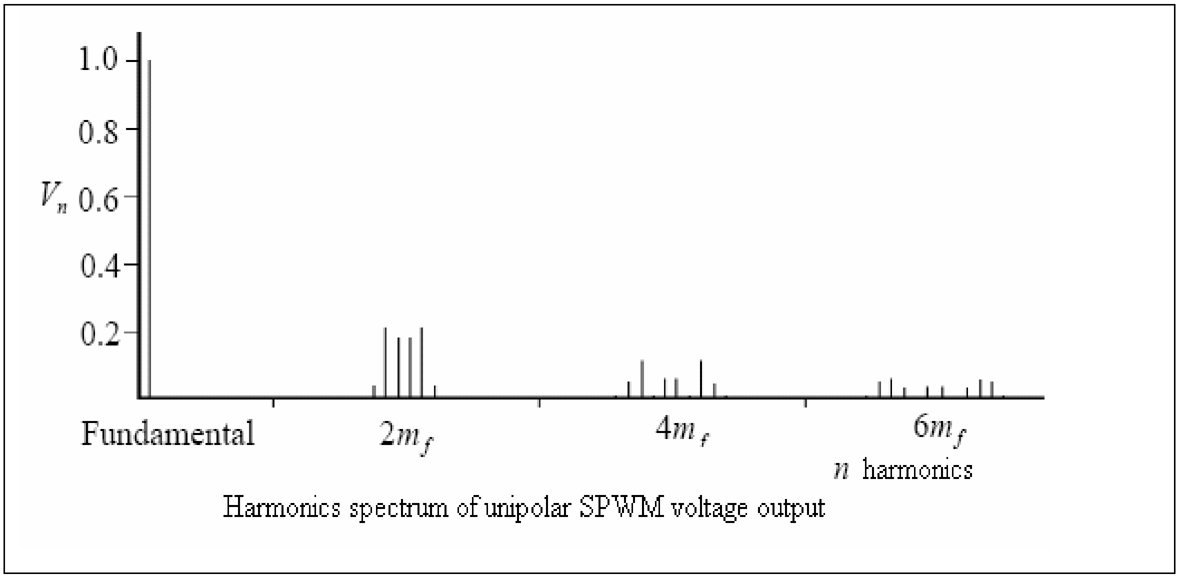

Figure 2.2 : Harmonics Spectrum of Unipolar SPWM

By comparing to the both harmonics spectrum of the swichings, it is best to apply the unipolar switching where the lower the THD current the better the output waveform.

2.3 PIC Microcontroller

A microcontroller is a single chip computer. *Micro* suggests that the device is small, and *controller* suggests that the device can be used in control applications. Another term used for microcontroller is *embedded controller*, since most of the microcontrollers are built into (or embedded in) the devices they control [6].

Microcontroller is general purpose microprocessor which has additional parts that allow them to control external devices. Basically, a microcontroller executes a user program which is loaded in its program memory. [6]

The reason for using microcontroller is general purpose microprocessor which has additional parts that allow them to control external devices. Basically, a microcontroller executes a user program which is loaded in its program memory.

Instead of using the microcontroller, PIC type of microcontroller architecture is distinctively minimalist. PIC microcontroller is the name for the microchip microcontroller (MCU) family, consisting of a microprocessor, I/O ports, timer (s) and other internal, integrated hardware. [6] It is characterized by the following features:

(i) Separate code and data spaces.
(ii) A small number of fixed length instructions.
(iii) Most instructions are single cycle execution (4 clock cycles), with single delay cycles upon branches and skips.
(iv) A single accumulator (W), the use of which (as source operand) is implied

(v) All RAM locations function as registers as both source and/or destination of math and other functions.

(vi) A hardware stack for storing return addresses.

(vii) A fairly small amount of addressable data space (typically 256 bytes), extended through banking.

(viii) Data space mapped CPU, port, and peripheral registers.

(ix) The program counter is also mapped into the data space and writable (this is used to synthesize indirect jumps).

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "**Programmable Interface Controller**", but shortly thereafter was renamed "**Programmable Intelligent Computer**" [7].

The PICs architecture has no (or very meager) hardware support for saving processor state when servicing interrupts. The 18 series improved this situation by implementing shadow registers which save several important registers during an interrupt. The PICs architecture may be criticized on a few important points:

(i) The few instructions, limited addressing modes, code obfuscations due to the "skip" instruction and accumulator register passing makes it difficult to program in assembly language, and resulting code difficult to comprehend. This drawback has been alleviated by the increasing availability of high level language compilers.

(ii) Data stored in program memory is space inefficient and/or time consuming to access, as it is not directly addressable.

2.3.1 PIC18F4550

Figure below shows the pin configuration of PIC18F4550. there were 40 pins with variable input /output configuration.

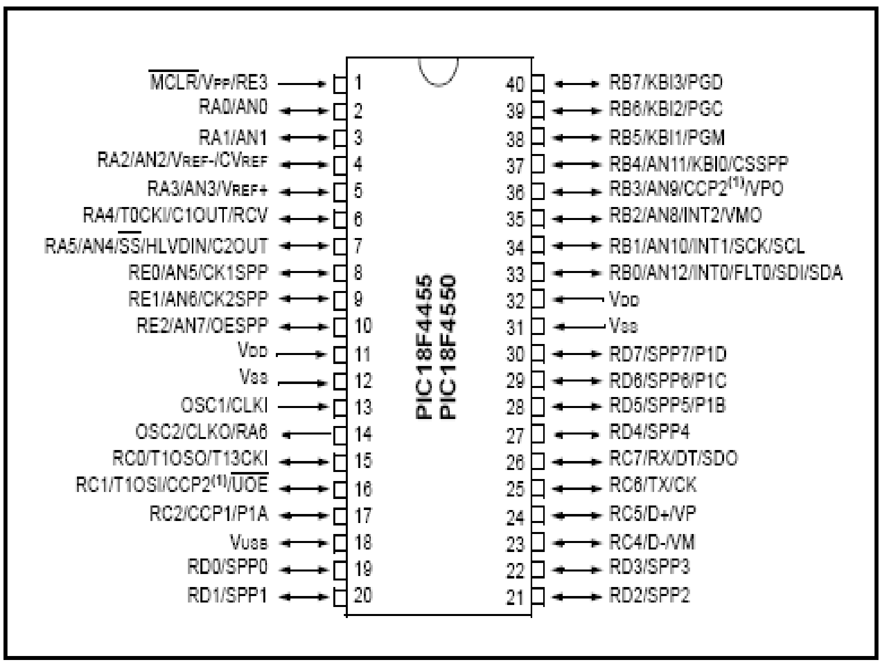

Figure 2.3 : PIC 18F4550 Pins Configuration

2.3.2 PIC18F4550 Peripherals

Table 2.1 shows some of its important parameters and features.

Table 2.1 : PIC 18F4550 features

Parameter Name	Value
Program Memory Type	Flash
Program Memory Size (Kbytes)	32
RAM	2,048
Data EEPROM (bytes)	256
I/O	35
Features	
Full Speed USB 2.0 (12Mbit/s) interface	
1K byte Dual Port RAM + 1K byte GP RAM	
Full Speed Transceiver	
16 Endpoints (IN/OUT)	
Streaming Port	
Internal Pull Up resistors (D+/D-)	
48 MHz performance (12 MIPS)	
Pin-to-pin compatible with PIC16C7X5	

2.4 Half_Bridge Inverter Topology

The half-bridge converter of Figure 2.4 can be used as an inverter. The number of switches is reduced to two by dividing the dc source voltage into two parts with the capacitors. Each capacitor will be the same value and will have voltage Vdc/2 across it. When s1 is closed, the load voltage is –Vdc/2. when s2 is closed, the load voltage is +Vdc/2. Thus, a square wave output or a bipolar pulse width modulated output can be produced [1].

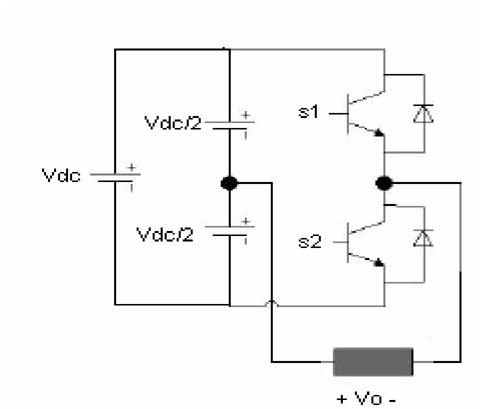

Figure 2.4 : Half-Bridge Inverter Circuit

2.5 Full Bridge Inverter Topology

Full bridge inverter is given the best topology to design a single-phase power inverter. By using power transistor such as IGBT or MOSFET it can give better output voltage than half bridge inverter. Figure 2.3 shows how the connection of full-bridge is made by using power transistor and PIC as a digital controller circuit.

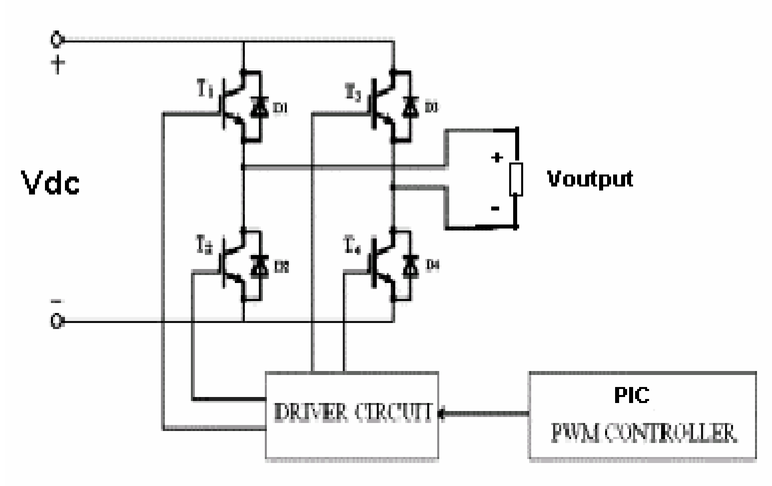

Figure 2.5 : Full Bridge Inverter Circuit

The circuit shows the full-bridge inverter with switches implemented as bipolar junction transistors with feedback diodes. Power semiconductor modules usually include feedback diodes with the switches [1].

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter explains how the software and hardware of this project is developed using the right procedures. Basically the hardware tools developed in this project not have many different from the previous project except for the part of PIC microcontroller circuit where the addition of analog controller has been made and the type of PIC itself has been changed to a better one with more advantages on it. Before going further through this report, let's look up the general idea of this project through the block diagram below.

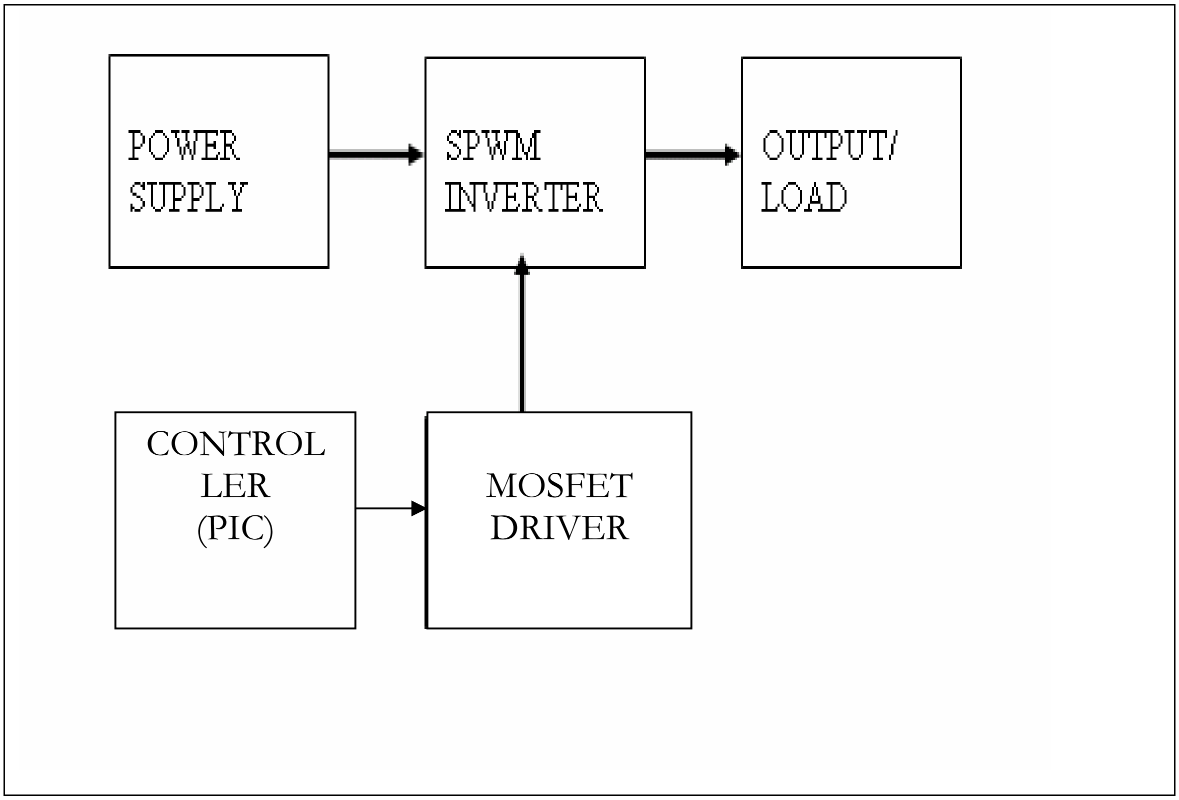

Figure 3.1: Basic Block diagram of the Project

Figure 3.1 shows the basic block diagram of the whole project. The design will accomplish through the use of high frequency switching and implementation of a microprocessor to digitally pulse our transistors. The PIC will give pulses that needed to drive the drivers hence control the switching scheme of the full-bridge inverter. The output of the load in the diagram is the speed of the motor.

3.2 Overall System Design

Design Specifications

Input Voltage	:	<300 V_{DC}
Output Voltage	:	Single-phase 240V_{AC} RMS
Output Frequency	:	40Hz , 50Hz and 60Hz
Output Power Range	:	>500Watts
Switching Frequency	:	Variable frequency, Variable dutycycle
PIC Controls	:	PIC 18F4550

The design specification above has many different compare to the previous design specification, although the hardware use is the same configuration. The frequency and duty cycle are variables in order to get the variable output frequency from the inverter.

3.3 SPWM Inverter

Spwm inverter is a better approach in designing an AC output compare to the square wave inverter and modified square wave inverter.

3.3.1 Theoretical operation of SPWM inverter

In SPWM inverter, the output voltage signal can be obtained by comparing a control signal, v_{cont} , against a sinusoidal reference signal, v_{ref} , at the desired frequency as shown in Fig 3.3 At the first half of the output period, output voltage takes a positive value (+ V_{dc}), whenever the reference signal is greater than the control signal. At the same way, at the second half of the output period, the output voltage takes a negative value (- V_{dc}) whenever the reference signal is less than the control signal [5].

The control frequency f_{cont} determines the number of pulses per half of cycle for the output voltage signal. Also, the output frequency O_f is determined by the reference frequency f_{ref}. The modulation index Ma is defined as the ratio between the sinusoidal magnitude and the control signal magnitude [5].

To obtain a vary train of pulses, each pulse has to vary proportional to the necessary fundamental component precisely at the time when this pulse occurs. The frequency of the output waveform needs to be higher than the frequency of the fundamental component. By varying the width of each pulse, the inverter is able to produce different levels of output voltage for the corresponding pulse event [5].

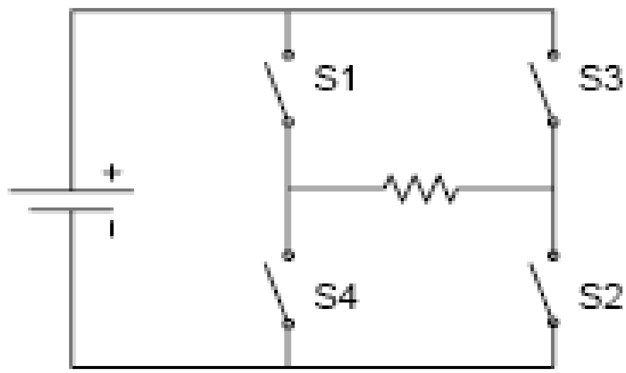

Figure 3.2 : Full Bridge Inverter

By referring to the Figure 3.2 above, we can apply unipolar switching scheme by control the switch as follows :

S1 is on when $v_{sine} > v_{tri}$

S2 is on when $-v_{sine} < v_{tri}$

S1 is on when $-v_{sine} > v_{tri}$

S2 is on when $v_{sine} < v_{tri}$

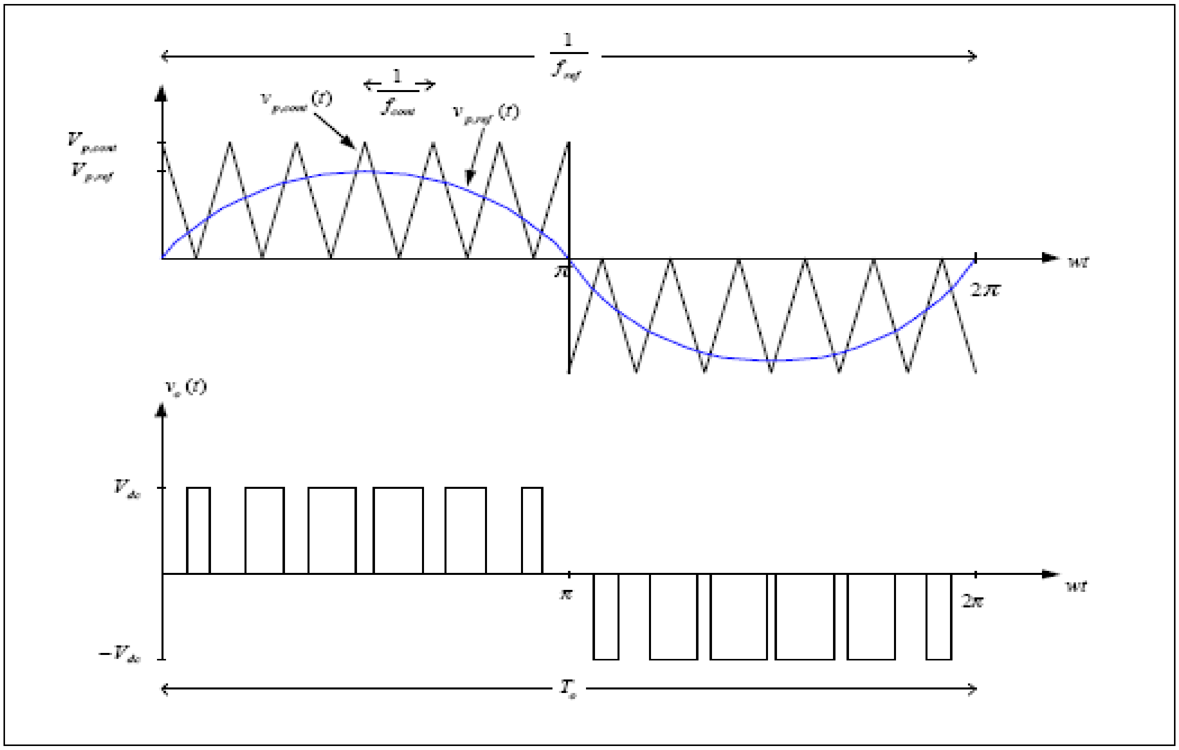

Figure 3.3 : Input and Output of unipolar SPWM Inverter.

3.3.2 PWM input/output

Pulse width modulation (PWM) analog signal can be used to pass analog data from a digital device. By varying wide pulses to indicate the actual voltage value, it is repeating signal that is on for a set period of time that is proportional to the voltage output. The higher the ratio of the pulse width to the periode (duty cycle), the more power deliver to the motor.

The inverter synthesizes an AC sine wave from the DC by the switching intervals. The small signal waveform from the PWM shapes the high voltage sinusoidal output waveforms that run the motor. The variable width pulses from the PWM also control the duration and frequency that the switches turn on and off. Frequency of carrier signal, also determine the resulting number of square notches in the output of the inverter. The amplitude of the synthesized sine wave is determined by the width of the resulting square wave. The relatives' widths of these square waves represent the applied voltage.

3.3.3 Strategy to Develop SPWM Switching Schemes

There are many ways to produce variable pulse width modulation besides using typical way, which is by comparing the reference signal with the modulation signal. Figures below will show you how to produce SPWM output. This method is a more straight forward way which still have many advantages.

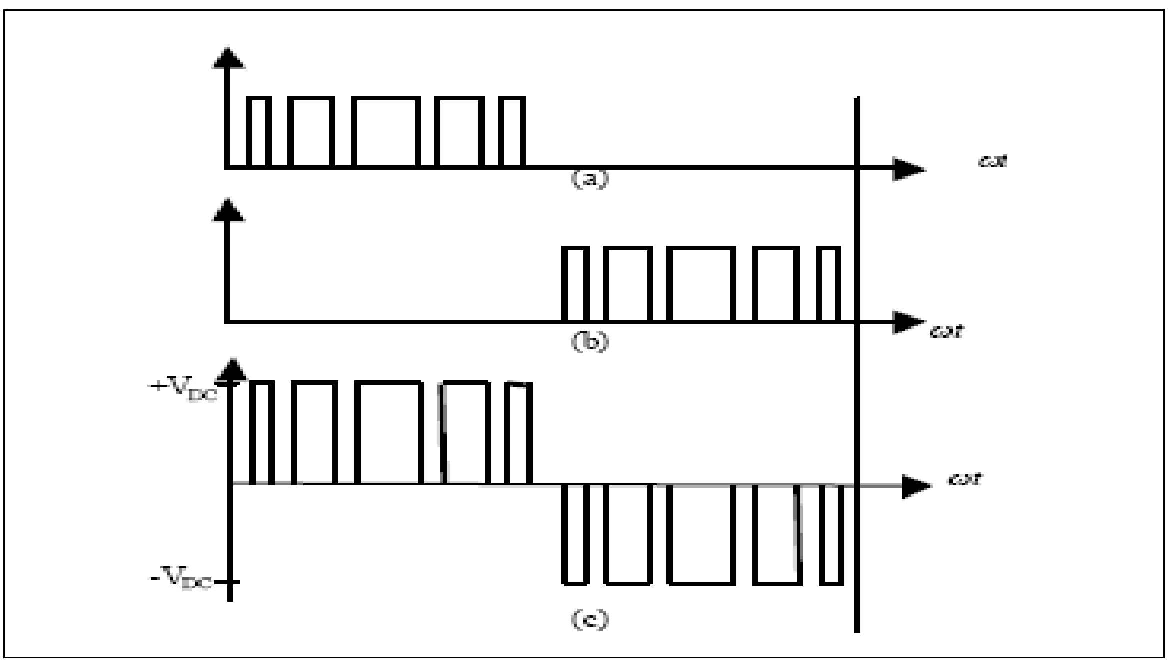

Figure 3.4: The switching signals; (a) Channel 1, (b) channel 2 and (c) the expected unipolar SPWM

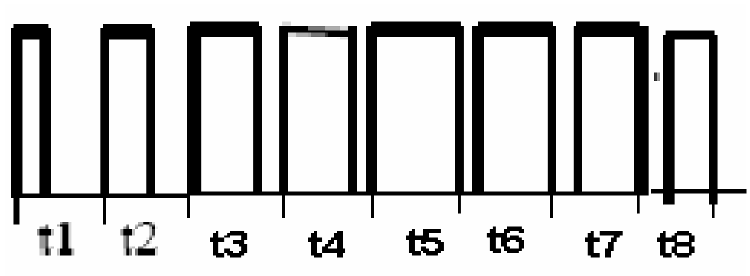

Figure 3.5: Graphical view of the switching pulses

The switching signals as shown in Fig. (a) and (b) are the desired SPWM signal for channel 1 and channel 2 respectively. Each channel is used to control a pair of inverter switches. The resultant output from a bridge inverter is shown in Fig. 1c. Designing switching pulses with high changes flexibility is the challenge in order to get the best approximation of the sinusoidal signal.

Each channel contributes half cycle of the inverter output waveform as illustrated in Fig. 3.4. This method eliminates the use of electronics component to generate the switching signals.

3.3.4 Design Method

The number of pulses, the switching time and the duty cycle generation are summarized in Table 1. The period for each cycle is fixed at certain calculated value and the duty cycle are then associated with the corresponding duty cycle. The switching